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16 June 1987
KG-87-0641 (86W-29)

Naval Research Laboratory
4555 Overlook Avenue, S.W.
Washington, D. C. 20375-5000

Attention: Mr. J. M. McMahon, Code 6501

Reference: Contract No. N00014-86-C-2530

Subject: Submission of R&D Progress Report and Financial Progress Report
for the period 28 March 1987 through 1 May 1987

Dear Mr. McMahon:

In accordance with CDRL Items A001 and A003 of the referenced contract, W. J. Schafer Associates, Inc. (WJSA) is pleased to submit herewith one (1) copy of the R&D Progress Report and Financial Progress Report for the period of 28 March 1987 through 1 May 1987.

Sincerely,

W. J. SCHAFER ASSOCIATES, INC.

Kenneth Griffin, Jr.
Contract Administrator

/eg

Enclosure

cc: Naval Research Laboratory
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Monthly Progress Report

April 1987

N00014-86-C-2530

During April WJSA interacted with NRL on the previously developed approach for examining the effect of autozoom on DF Pulsed Chemical Laser (PCL) performance as it applied towards investigating the Boeing RPDF configuration, including the illumination profile that Boeing measured in RPDF. The key questions addressed were:

To what extent is autozoom a problem in a 40 cm initiation height device?

Would the F_2 profile Boeing selected serve to achieve the goal of a uniform $D_2 + F_2$ burn throughout the cavity?

Are there other performance robbing processes associated with non-uniform initiation?

To answer those questions an approach had been developed to model the three dimensional illumination intensity distribution within the gain medium, first without, and then with fluorine present; both in an untailored uniform 16 percent concentration, and in a tailored profile with a 16 percent average fluorine concentration.

Having developed the model for examining F_2 tailoring, the need was found to use an illuminator that more closely matched the actual output profile of the Boeing device. From the Boeing report it was determined that a 54 x 74 cm illuminator would be appropriate since these dimensions corresponded more closely to the actual dimensions of the window separating the flashlamps and reflectors from the laser cavity.

The Boeing report contained some data on the initiation profile produced by their flashlamp configuration. This data was in the form of a curve of relative intensity versus distance from the center of the flash head. The data was measured with a silicon detector using uv bandpass filters centered at 230 and 310 nm. The measurements were made in the absence of F_2 , and thus do not show the effects of F_2 absorption. The original purpose of the measurements was to determine the amount of illumination absorbed by the flashlamp windows.

It is impossible to exactly model the Boeing illumination profile due to the lack of information as to what that profile really was. What was really needed was a complete measurement of the illumination profile throughout the cavity. Even a single additional curve similar to the one given, except measured from a different reference point such as along a line through one of the outside corners, would have proved extremely helpful and no doubt, enabled better characterization of the true profile.

Working with the information given, it was determined through the use of Lotus 123, that the Boeing profile along the central line could be

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matched very closely by placing the 54 x 74 cm uniform diffuse illuminator at a distance of 57 cm, which corresponded to twice the distance from the edge of the medium to the flash-head in the actual device (28.5 cm). Whether or not this configuration yields a similar degree of accuracy elsewhere in the cavity cannot be determined without additional experimental data.

Using this illumination profile it was determined that the fluorine tailoring profile chosen by Boeing was, in fact, well suited to producing a uniform chemical burn within the cavity. However, beam quality calculations conducted by George Hall of NRL, using time dependent index of refraction values provided by this current study, indicated that fluorine tailoring may not have been necessary. This was a consequence of the fact that the index of refraction gradients produced by non-uniform initiation are not random fluctuations but rather a smoothly varying function of position within the gain medium. This suggests that the beam quality problems encountered by Boeing arose from some other cause.

This study raised several open issues worthy of future investigation:

At what initiation height x F_2 concentration does autozoom become a non-negligible effect?

Do flashlamp arrays produce ripple patterns in illumination yielding harmful index of refraction gradients?

Does uneven burn produce serious mismatch between oscillator and amplifies sections of an unstable resonator?

If achieving a constant pump parameter necessitates a gradient in atom concentrations as $I.F_2.F_2 = F.F_2$ is maintained at a constant value, does D atom deactivation of DF defeat the purpose of fluorine tailoring?

The last three issues suggest explanations for the unexpectedly poor performance of RPDF in terms of joules/liter and beam quality, particularly the latter two issues. PULSDF runs indicated that even a relatively minor deviation in pump parameter, from one region to another, could lead to a serious mismatch in terms of synchronizing the gains on individual laser transitions. As a result, a laser line could have gain in one region (for example in the perhaps more weakly initiated oscillator section), while it is experiencing heavy loss in the part of the unstable oscillator serving as an amplifier. The resulting absorption would not only lead to a significant loss of power; it would, in fact, aggravate the mismatch further by accelerating the chemical burn already racing ahead in the amplifier section by producing additional gas heating in that zone.

These results were presented to PMW-145 at a program review conducted on April 30, 1987 and are described in detail in a report

entitled "DF Pulsed Laser Autozoom Calculations: Boeing Configuration" issued on April 17, 1987.

To fully explore their impact a detailed chemistry in the cavity resonator analysis would be required. Fortunately just such an exploration is to be conducted in the immediate future. During April a detailed task plan was constructed for resonator assessment as part of an overall DF PCL assessment. This task plan was also presented to PMW-145 on April 30, 1987.

There is multi-fold motivation for investigating the cavity/chemistry interaction. In part it may clarify the as yet unresolved issue as to whether energy scales as 4 or 8 times the pump parameter. To date Fabry-Perot cavity results indicate 8 times pump parameter scaling, while unstable resonator results yield 4 times or worse. This suggests that cavity/chemistry interactions may be a problem.

Only such a cavity/chemistry approach can lead to an accurate assessment of performance factors, such as the potential loss of output energy due to non-uniform initiation causing lines lasing in the oscillator region to be absorbed in the amplifier section of an unstable resonator. A related issue is the effectiveness of carefully positioning the resonator feedback region to minimize the role of non-uniform initiation.

Detailed cavity/chemistry calculations are also the only way to acquire accurate predictions of time resolved output spectra as a function of operating parameters such as: initiation strength/duration; resonator configuration; fuel mixture, and spectral control. The resulting output spectrum has a major effect on beam control/propagation/damage and vulnerability.

DF PCL behavior tends to seriously complicate any such chemistry/cavity resonator analysis. The DF laser transition manifold is a complex system of coupled cascades with linked gain behavior along cascades and linked gain behavior between cascades. The gain on a single line does not sustain a steady state for any appreciable length of time. In only 1/3 of the active period for a given transition does the gain equal the cavity loss or threshold gain. This makes the use of "average" of g_0 and I_{SA} very questionable. Even moderately non-uniform initiation produces problems in DF PCL's. As has been discussed, lines with gain in one region may be lossy in others. Absorption of lasing in such lossy regions must be managed. Cavity characteristics add further complications. With the external mirrors window absorption is critical. The use of intracavity absorbers can affect gains greatly.

The task plan proposed for the gain generator section of the resonator assessment would begin by anchoring the PULSDF code to available PCL performance data. WJSA will obtain TRW data gathered in the past year and a half. Key PULSDF parameters will be varied to get good agreement with data. PULSDF runs conducted during April indicate that PULSDF gives exceptionally good agreement with overall pulse energy and

pulse shape for RPCL when it is operated with sapphire windows. Such windows strongly suppress lasing on longer wavelength transitions associated with high rotational levels in lower vibrational states or high vibrational levels. Such transitions have been somewhat problematic for PULSDF in the past, eliminating them with sapphire windows revealed the code's strengths. But it still remains to be determined if PULSDF is accurate on a line by line basis with respect to intensity and temporal behavior. To that end, WJSA will model the DF PCL spectral profile as a function of time for various operating conditions which TRW investigated.

Also required for careful analysis of the TRW experiments will be the data TRW collected on UV intensity as a function of position within the cavity. This data comes primarily from "Schackelford Sphere" measurements. The results of the TRW illumination model will also be considered together with the F atom production/uniformity measurements with TRW carried out.

In varying key PULSDF parameters, to get good agreement with data, special emphasis will be placed upon the temporal behavior of the overall pulse and accurate time resolved spectral output. The most important kinetics parameters to be analyzed include: the overall rate and temperature dependence of the "Hot" reaction $D + F_2 \rightarrow DF + F$; the fraction of DF self-deactivation that proceeds VV as contrasted with VT; the extent of DF deactivation by D atoms; the rotational relaxation rate - its cross section and energy defect dependence; the possibility of F_2 dissociation by high vibrational levels of DF or D_2 and other proposed chain branching mechanisms; and O_2 atom scavenging reaction rate coefficients.

PULSDF will be upgraded to address the cavity/chemistry interaction by streamlining the way reactions are treated, preposing PULSDF to interact with the resonator code PULRES, and constructing needed graphical representations of cavity/chemistry convergence.

A code name DEALER will be constructed to serve as the PULSDF/PULRES interface. DEALER will perform the necessary assembly of results from $8 \times 8 \times 3$ separate PULSDF runs. It will feed the resonator code gain information in a way that takes into account storage limitations of the CRAY, the access/read time of the CRAY, and the most effective overall approach for the resonator code. DEALER will perform similar tasks in allocating the results of the resonator run back to 192 PULSDF runs.

PULSDF will also be updated to make efficient use of the CRAY vectorizing capability (it was originally optimized for use on the Texas Instruments Advanced Scientific Computer TI-ASC). The use of a more efficient numerical integrator will also be investigated.

Simultaneously with this activity WJSA has initiated a component technology assessment. This will be coupled with the code development to assess the limits of PCL scaling.

In the PCL beam control activity, the first order scenario analysis has been completed. Nominal pulse energies, pulse repetition rates, and

aperture diameters can now be specified for both escort and self defense scenarios. As this analysis involves nonlinear atmospheric propagation and a fairly large number of variables, we restricted the analysis to a set of discrete values of the primary parameters and nominal atmospheric parameters. As the RPCL generates a broad spectrum of lines (some highly absorbed by the atmosphere), atmospheric absorption was also varied to assess the degree of "line filtering" that will be required.

Several hundred cases were considered in the analysis. A new approach for presenting such a large quantity for scenario analysis data has been developed. This approach appears to allow an easily understood and direct approach to selecting the system operating parameters such as pulse repetition rate, pulse energy, aperture diameter, maximum effective atmospheric absorption and maximum jitter. Sensitivities to various parameters are also easily seen.

These results were presented at the PCL Review on 30 April 1987 at NRL. The scattering value of 0.2 for maritime scenarios was considered too high by some of the reviewers. During May, we will address sensitivity to scattering.

In the optics area work was centered in two major areas. Errors were found in the inputs to the THERM window code which we found during an attempt to use it to analyze a window. We are fixing this. We also attended a kickoff at Bell Aerospace for the large cooled optics heat exchanger program.

WJSA personnel attended the Preliminary Design Review (PDR) of the HELVBES Phase 2 program, conducted at United Technologies Optical Systems (UTOS) on 29 and 30 April 1987. The key element of the HELVBES system design is the material window. The preliminary design approach presented by UTOS is driven by an empirically determined peak allowable flux level that will not initiate coating/window interface damage. Calculated pressure and thermal stresses are sufficiently low such that both fast fracture and slow crack growth phenomenon should not be a limiting factor. A slightly oversimplified view of the design logic was to increase the window size to a maximum to reduce the peak irradiance levels and then to segment (2 pieces) the window to reduce material cost and fabrication cost and risk. The segmented window also reduced the maximum pressure stress for a given window thickness.

The calculation of pressure stress is relatively straight-forward. However, the thermal stress calculation depends on the bulk absorption and surface absorption coefficients. The bulk absorption specification should be verified prior to acceptance of the window.

The weak link in the system is the uncertain peak irradiance level that may be expected in the beam as a function of power level and propagation distance. Since the cause of window failures at the coating window interface is not completely understood, the specification for surface finish, flaw tolerance and coating characteristics should be made as tight as possible. Each specification should be assessed as to cost

impact and tightened as long as safety margin for unknown phenomenon exist. The empirically determined maximum allowable irradiance does reduce the system throughput power capability.

The contractors suggestion to measure the beam profile at the material window location prior to irradiating the window has considerable merit. A possible solution would be to propagate a low power sample over the equivalent distance and measure its peak-to-average intensity characteristics.

During the month of April, the major effort under the PLDS task was the continuation of the review of the diagnostic proposed by AVCO and Rocketdyne for the Master Oscillator Testing to be conducted at WSMR at the end of the calendar year. At an initial meeting, Rocketdyne briefed essentially the same diagnostics bench as was proposed over two years ago and repropose last year. The WJSA assessment of this configuration is that it is complex, contains a large number of beam splitter and 450 angle turning flats (up to 30 surface for the MO output to the far field diagnostics) and would be hard to make work on a condensed schedule. AVCO proposed a simpler approach and the team has been reconciling the differences. The most recent optical layout have incorporated many of suggestions and now has a reasonable chance of working to an acceptable level in time for the first testing of the master oscillator. This layout now includes the OMA available from WSMR and a reduced capability Power-in-the-Bucket (PIB) diagnostic.

Rocketdyne proposes to construct a stand alone diagnostics table with all diagnostic measurement being taken simultaneously on all tests. This is probably too complex to complete within the schedule. No attempt to phase the installation of instruments or to address the problems of integrating the diagnostics at WSMR has been made to date. At the most recent equipment list review, Rocketdyne added a number of new requirements. These are: 1) a wide angle scatter measurement system, 2) a background sampling system, 3) a diagnostics calibration system, 4) a digital interface simulator, and 5) a separate diagnostics system alignment laser. While each of these may be desirable, it is not clear what is the minimum set that EMRLD needs.

During April we set up the analytical framework for our work on the optical improvement program. In addition, we have begun collecting data on potential laser facilities where tests could be carried out to, for example, establish the degree of hardness and capabilities of optical filter systems. We have not yet received the additional documentation and information on detailed aspects of the optical improvement program that were requested in March.

WJSA initiated development of goals for survivable sensors. In support of that WJSA personnel attended the EOCM Colloquium and IRIS Symposium on Infrared Countermeasures. To support DARPA in these areas, WJSA updates the security guide, and participated in the solid state laser and applications reviews held at Livermore. WJSA continued to evaluate concepts and countermeasures for a Euryale system.

In support of APACHE, WJSA visited KMS Fusion to discuss the experimental program TRW planned to do there. Assessment of those efforts were provided to the government under separate cover.

DATE	TRAVELER	LOCATION	PURPOSE
4/1-2	J. Birkitt	WSMR	Technical Discussions
4/1-2	J. Stregack	KMS Fusion	Technical Discussion
4/2	D. Crawford	WJSA/Boston	PCL Discussions
4/6-8	E. Kuhl	APL	IRIS Meeting
4/7-9	J. Birkitt	WSMR	Technical Support
4/9-10	J. Stregack	WSMR	Technical Discussions
4/13-15	J. Birkitt	WSMR	Technical Support
4/14-17	D. Friedman	LLNL	Tactical/Solid State Laser Review
4/15-16	F. Tart	WSMR	Technical Discussions
4/28-30	J. Walters	NRL, WJSA/WASH	PCL Review
4/28-29	K. Shillito	Bell Aerospace	Mirror Review
4/28-30	G. Hart	NRL	PCL Review
4/29-30	G. Callahan	UTOS	HELBES PDR
4/29-30	J. Albers	NRL, WJSA/WASH	PCL Review
4/29-30	J. Stregack	UTOS	HELBES PDR